

Comparison of Femoral Morphology and Bone Mineral Density between Femoral Neck Fractures and Trochanteric Fractures

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Abstract

Background Many studies that analyzed bone mineral density (BMD) and skeletal factors of hip fractures were based on uncalibrated radiographs or dual-energy x-ray absorptiometry (DXA).

Questions/purposes Spatial accuracy in measuring BMD and morphologic features of the femur with DXA is limited. This study investigated differences in BMD and morphologic features of the femur between two types of hip fractures using quantitative computed tomography (QCT).

Patients and Methods Forty patients with hip fractures with normal contralateral hips were selected for this study between 2003 and 2007 (trochanteric fracture, n = 18;

femoral neck fracture, n = 22). Each patient underwent QCT of the bilateral femora using a calibration phantom. Using images of the intact contralateral femur, BMD measurements were made at the point of minimum femoral-neck cross-sectional area, middle of the intertrochanteric region, and center of the femoral head. QCT images also were used to measure morphologic features of the hip, including hip axis length, femoral neck axis length, neck-shaft angle, neck width, head offset, anteversion of the femoral neck, and cortical index at the femoral isthmus.

Results No significant differences were found in trabecular BMD between groups in those three regions. Patients with trochanteric fractures showed a smaller neck shaft angle and smaller cortical index at the femoral canal isthmus compared with patients with femoral neck fractures.

Conclusions We conclude that severe osteoporosis with thinner cortical bone of the femoral diaphysis is seen more often in patients with trochanteric fracture than in patients with femoral neck fracture.

Levels of Evidence Level IV, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This work was performed at Osaka Minami Medical Center, Osaka, Japan.

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Introduction

Proximal femoral fractures in the elderly population are a major public health problem given the known associations with increased mortality, morbidity, and healthcare costs [8]. For prevention of proximal femoral fractures, understanding of the etiology and bone strength features of these patients is essential. Proximal femoral fractures can be classified into femoral neck fractures and trochanteric fractures. These two types of fractures may show different

etiologies [25]. Koval et al. reported women who sustained a trochanteric fracture were more likely to be older, less independent in activities of daily living, and to have used ambulatory assistive aids at home before hip fracture compared with women who sustained a femoral neck fracture [21].

Reduction in bone mineral density (BMD) is considered one of the major risk factors for a femoral fracture [13, 24]. Furthermore, risk factors of a proximal femoral fracture may be associated with femoral geometry and BMD values [9]. Several studies have shown that variations in femoral geometric measurements such as hip axis length (HAL) [14], neck shaft angle (NSA) [2], and femoral neck width are associated with increased risk of proximal femoral fractures [16, 18]. Gnudi et al. reported, in a DXA study, that patients with proximal femoral fractures showed longer HAL, wider femoral neck width, and larger NSA than the control group [18]. Conversely, Panula et al. found no relationships between fracture risk and skeletal factors such as HAL, NSA, and femoral neck diameter [28].

Some studies have indicated the probability of either fracture is a function of BMD and/or skeletal factors that may differ between the two types of fractures [13, 16, 18, 26, 32, 33]. In a DXA study, Gnudi et al. found patients with femoral neck fractures showed longer HAL and larger NSA than patients with a trochanteric fracture [18]. Mautalen et al. reported trochanteric fractures are more related to severe osteoporosis mainly in the trabecular compartment, whereas cervical fractures are more related to pelvic and hip geometry [25]. Gnudi et al. reported women with trochanteric fractures had lower BMD in the femoral neck and trochanteric regions, shorter HAL, and more varus NSA than women with femoral neck fractures on DXA [16].

These prior studies all are based on uncalibrated radiographs or DXA. Spatial accuracy in measuring BMD and morphologic features of the femur on DXA is limited, because DXA provides only projected 2-D images. Unlike 2-D DXA or plain radiographs, QCT offers the ability to reconstruct true AP views for measuring true morphologic features of the femur and BMD of cortical and trabecular bone with 3-D precision [1, 6, 7, 20, 23, 31], although QCT BMD measurements at the hip are not yet clinically practical for prediction of fracture risk [12].

The current study aimed to quantify differences in trabecular BMD and differences in femoral geometry using QCT, a spatially more accurate method, in Japanese patients with femoral neck fractures and trochanteric fractures. Our research questions included whether there are predictable differences in BMD in three regions of the proximal femur when femoral neck and intertrochanteric fractures are compared and whether there are consistent

differences in measures of proximal femoral geometry, including HAL, femoral neck axis length, NSA, and cortical index of the femoral isthmus when intertrochanteric and femoral neck fractures are compared.

Patients and Methods

Consecutive patients with unilateral hip fractures who were admitted to one of our clinics were candidates in this study. Patients with hip fractures resulting from low-energy falls sustained while walking or standing and a normal contralateral hip were included in this study. Patients with hip fractures resulting from high-energy falls were excluded from this study. Patients with previous contralateral hip fractures or metabolic bone disease other than senile osteoporosis and postmenopausal osteoporosis or inflammatory arthritis such as rheumatoid arthritis also were excluded. Permission for this study was obtained from the hospital ethics committee and informed consent was obtained from each patient. Based on these criteria, 40 patients with hip fractures (nine men, 31 women; mean age, 77.9 years; range, 57–97 years) comprised the study.

Mean height was 152.3 cm (range, 137–170 cm), mean body weight was 49.1 kg (range, 35–71 kg), and mean body mass index was 21.1 kg/m² (range, 13.7–26.4 kg/m²). Trochanteric fractures were present in 18 patients (four men, 14 women; mean age, 79.2 years; range, 64–97 years) and femoral neck fractures were present in 22 patients (five men, 17 women; mean age, 76.8 years; range, 57–96 years). Among the demographic parameters, there were no significant differences in mean age, gender, height, weight, or body mass index between patients with trochanteric and femoral neck fractures (Table 1).

All 40 patients completed a preoperative CT within 2 days of admission. Scans were acquired using a multi-detector CT scanner (Light Speed CT; GE Medical Systems, Easton, CT) with a standardized protocol scanning from the iliac crest to the knee. Scanning parameters were 120 kVp, 350 mA, slice thickness of 2.5 mm, and 512 × 512 matrix in a spiral reconstruction mode with a

Table 1. Characteristics of the two groups

Parameter	Trochanteric fracture	Femoral neck fracture	p Value
Female/male	14/4	17/5	0.99*
Age (years)	79.2 ± 8.7	76.8 ± 9.8	0.39†
Height (cm)	150.2 ± 7.3	154.0 ± 8.1	0.12†
Weight (kg)	46.4 ± 5.8	51.2 ± 8.9	0.05†
BMI (kg/m ²)	20.6 ± 2.4	21.5 ± 2.9	0.27†

Values are mean ± SD; * Fisher's test; †Mann-Whitney U-test; BMI = body mass index.

36-cm field of view. A calibration phantom (B-MAS 200; Kyoto-Kagaku, Kyoto, Japan) was included during CT. This phantom contained five chambers filled with different concentrations of hydroxyapatite (0, 50, 100, 150, and 200 mg/cm³) and was placed under the buttock to encompass the region from the femoral head to the lesser trochanter. A midcoronal multiplanar reconstructed (MPR) view of the uninjured contralateral proximal femur through the femoral head center, center of the femoral neck, and center of the femoral canal isthmus was reconstructed using commercially available image analysis software (Virtual Place-M; Medical Imaging Laboratory, Tokyo, Japan). Three MPR views perpendicular to the midcoronal view and femoral neck axis through the femoral head center and center of the femoral neck isthmus were reconstructed manually by measuring the maximum diameter of the femoral head and minimum diameter of the femoral neck to measure BMD at the point of cross-sectional area at the femoral head center (Fig. 1A), the point of minimum femoral-neck cross-sectional area (Fig. 1B), and cross-sectional area at the middle of the intertrochanteric region through the lesser trochanter peak (Fig. 1C). Trabecular BMD was measured by tracing the trabecular region. Intensity of femoral bone area in the cortex through

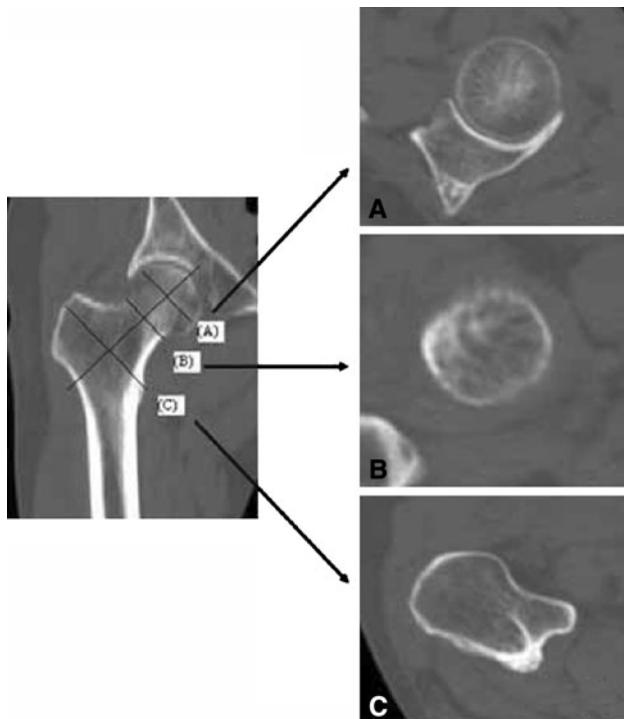


Fig. 1A–C Three multiplanar reconstructed views perpendicular to the midcoronal view and femoral neck axis through the femoral head center and center of the femoral neck isthmus were captured to measure (A) bone mineral density at the femoral head center, (B) the point of minimum femoral-neck cross-sectional area, and (C) the middle of the intertrochanteric region through the lesser trochanter.

these MPR views was measured and calibrated with phantom images to obtain the BMD [31].

We also used the CT images to measure the following aspects of morphologic features of the hip: HAL, defined as the length along the femoral neck axis from the lateral aspect of the greater trochanter to the inner pelvic rim (AE in Fig. 2); femoral neck axis length (FNAL), defined as the length of the neck axis between the head center and the femoral medullary axis (BF in Fig. 2); NSA defined as the angle between the femoral neck (BF in Fig. 2) and the femoral shaft (FG in Fig. 2); neck width; head offset (BB' in Fig. 2); anteversion of the femoral neck defined as the axial angle between the neck axis on the CT image through the medial head-neck junction and the posterior femoral condylar line [30]; and cortical index (CI) at the femoral isthmus (isthmus CI; Fig. 3) [2]. CI was defined as the ratio of the femoral diaphyseal diameter minus the intramedullary canal diameter over the femoral diaphyseal diameter [10]. To compare the differences in BMD at the femoral head center and isthmus CI between the injured side and uninjured contralateral side, these parameters also were measured on the injured side. All measurements were made by the same observer (YM). The reproducibility of similar BMD measurements with QCT was reported to be 5.4% for trabecular BMD in the intertrochanteric region [5].

We compared BMD measured in these three regions of the proximal femur and these measures of femoral

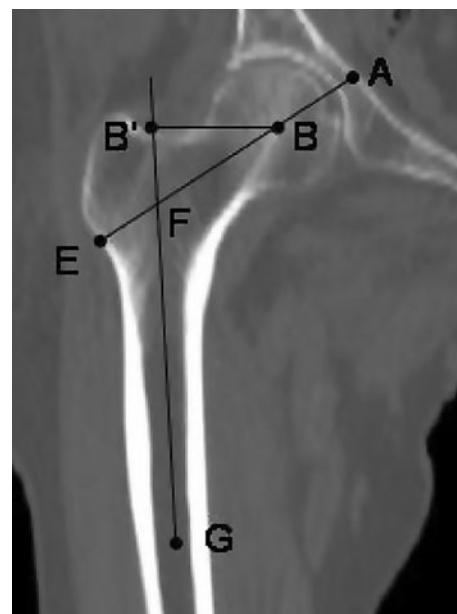


Fig. 2 CT images were used to measure morphologic features of the hip: head axis length (HAL), defined as the length along the femoral neck axis from the lateral aspect of the greater trochanter to the inner pelvic rim (AE); femoral neck axis length (FNAL), defined as the length of the neck axis between the head center and the femoral medullary axis (BF); neck-shaft angle (NSA); neck width; and head offset (BB').



Fig. 3 The cortical index (CI) at the femoral isthmus is shown. The CI equals the ratio of the femoral diaphyseal diameter minus the intramedullary canal diameter over the femoral diaphyseal diameter: isthmus CI = $(I-H)/I$.

geometry between cases of trochanteric fractures and femoral neck fractures. Statistical analysis of each parameter for trochanteric fractures and femoral neck fractures was performed using the Mann-Whitney U test. Parameters with *p* values less than 0.05 were considered as statistically significant.

Results

No significant differences in trabecular BMD were seen between groups when measured at the femoral head, femoral neck, or intertrochanteric region (Table 2).

Of the measures of femoral geometry, only one variable showed a difference between the fracture types. CI at the isthmus was significantly lower in the trochanteric fracture group than in the femoral neck fracture group (*p* = 0.02). NSA was smaller in the trochanteric fracture group than in the femoral neck fracture group, but the difference was not significant (*p* = 0.05) (Table 3). Femoral head offset (Fig. 2) tended to be larger in the trochanteric fracture group than in the femoral neck fracture group, although the difference was not significant. HAL, FNAL, and neck width did not differ significantly between groups. BMD at the femoral head center and isthmus CI on the injured side were $115.0 \pm 47.7 \text{ mg/cm}^3$ and 0.41 ± 0.07 in the trochanteric fracture group and $148.1 \pm 42.5 \text{ mg/cm}^3$ and 0.46 ± 0.09 in the neck fracture group. There were no

Table 2. Comparison of BMD at different regions between the two patient groups

Parameters	Trochanteric fracture	Femoral neck fracture	<i>p</i> Value
Number	18	22	
BMD at head (mg/cm^3)	126.7 ± 45.2	127.3 ± 29.4	0.76
BMD at neck (mg/cm^3)	84.7 ± 59.1	88.8 ± 45.1	0.41
BMD at intertrochanter (mg/cm^3)	44.3 ± 25.2	59.9 ± 27.1	0.10

Values are mean \pm SD; BMD = bone mineral density.

Table 3. Comparison of hip geometry between patient groups

Parameters	Trochanteric fracture (n = 18)	Femoral neck fracture (n = 22)	<i>p</i> Value
HAL (mm)	104.3 ± 8.9	108.1 ± 7.4	0.18
FNAL (mm)	47.4 ± 4.3	47.7 ± 4.5	0.96
NSA ($^\circ$)	125.6 ± 5.6	129.1 ± 3.7	0.05
Neck width (mm)	28.0 ± 2.8	28.2 ± 2.6	0.96
Head offset (mm)	38.0 ± 4.6	36.4 ± 4.0	0.28
Anteversion ($^\circ$)	19.3 ± 11.1	24.3 ± 7.2	0.15
Isthmus CI	0.42 ± 0.07	0.47 ± 0.08	0.02

Values are mean \pm SD; HAL = hip axis length; FNAL = femoral neck axis length; NSA = neck shaft angle; CI = cortical index.

significant differences in these parameters between the injured and uninjured sides in either fracture group.

Discussion

This study aimed to quantify the differences in trabecular BMD and femoral geometry between the intertrochanteric fracture group and femoral neck fracture group using QCT with 3-D precision.

Our study has some limitations. First, this series measured BMD and morphologic features of the hip not on the fractured side, but on the contralateral side. However, morphologic features of the femur and BMD on both sides generally are considered similar unless one side shows bone disease or a history of trauma. We also confirmed that there were no significant differences in BMD at the femoral head center and isthmus CI between the injured and contralateral uninjured sides in this study. Second, this study included females and males as subjects. BMD and structural parameters usually are greater in males than in females, and therefore evaluation of these values after dividing subjects into male and female groups would be preferable. However, we considered that the mixture of males and females had little impact on these values, because no significant differences in gender distribution

were apparent between groups. Third, this study was not an age-matched study, because these two fractures have different etiologies [25] and the mean age in subjects for onset of each fracture differs. However, this does not appear to be of significance, because the purpose of this study was to characterize BMD and morphologic features between trochanteric and femoral neck fractures. Fourth, the total number of patients is small and some of the measurements were just significant or close. Larger numbers would help in the discrimination between two groups. Fifth, there is a paucity of literature to support the advantages of QCT for prediction of hip fractures over DXA; however, QCT has become a useful research tool for analyzing hip geometry and measuring BMD.

Although some studies have evaluated correlations of femoral strength with BMD and morphologic features of the femur using QCT [1, 4–7, 15, 22, 23], our study, in which Asian people were surveyed, is unique from the perspective of evaluating BMD and morphologic features of the femur using 3-D QCT in detail with comparison of trochanteric and femoral neck fractures. In our study, when patients with trochanteric fractures were compared with patients with femoral neck fractures, trabecular BMD values among groups were not significantly different in the femoral head, femoral neck, and intertrochanteric regions. However, isthmus CI was significantly lower in patients with trochanteric fractures than in patients with femoral neck fractures. If one assumes that CI represents cortical bone strength [10], this suggests that cortical bone strength was much poorer in the trochanteric fracture group than in the femoral neck fracture group. From the results, differences existed in cortical bone strength rather than trabecular BMD comparing trochanteric fractures and femoral neck fractures. Lower trabecular BMD at the intertrochanter area may be a secondary factor contributing to trochanteric fracture, although our study showed no significant difference in this measure.

In terms of morphology, some authors have reported that longer HAL and/or FNAL are risk factors for proximal femoral fractures [16, 18]. This is because a longer lever arm is considered to increase the risk of fracture on impact [3]. As HAL increases, the lever arm between the hip center and the femur extends and fractures can occur with the excess load on the proximal femur [9]. Although patients with femoral neck fractures have been reported to show longer HAL [11, 16–18], when compared with patients with trochanteric fractures, no significant differences in lever arm indices such as HAL, FNAL, or head offset were found between groups in our study. We found lever arm indices are not sufficiently characteristic to differentiate between the two types of proximal femoral fractures. The lever arm parameters are unstable on 2-D measurements because they can be changed easily by

patient positioning and femoral anteversion. The difference between 2-D and 3-D measurements may be the reason for the different findings of lever arm parameters in our study.

However, our patients with trochanteric fractures showed a smaller NSA than patients with femoral neck fractures, although the difference was not significant ($p = 0.05$). Isaac et al. [19] and Norkin and Levangie [27] reported NSA tends to decrease during aging. We could not clarify whether these morphologic features are primary or secondary to remodeling. Osteoporosis often accompanies osteomalacia in the elderly as a result of mild malabsorption of vitamin D [29]. Patients in the trochanteric fracture group thus might have shown severely decreased cortical strength and increased levels of unmineralized bone, leading to changes in the femoral neck to a varus presentation.

Also, theoretically, if HAL or FNAL shows similar values between groups, decreases in NSA will relatively increase head offset between the hip center and femur, increasing the risk of fracture on impact. In our study, however, differences in NSA between groups were too small to reveal any significant differences in lever arm parameters. Significant differences in NSA or head offset may be identifiable between groups with larger subject populations.

The results of our study cannot be used to identify risk factors for hip fractures, because details of BMD and 3-D morphologic features of the hip in the healthy elderly population remain unknown. Further studies are needed to compare BMD and morphologic features of the hip in fracture groups and healthy elderly populations. However, we believe that patients who sustain trochanteric fractures may have greater compromise of cortical bone versus cancellous bone reflected by a lower CI in the femoral isthmus when compared with patients who sustain femoral neck fractures.

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